Project VeSElkA: Analysis of Balmer line profiles in slowly rotating chemically peculiar stars[1]

V. Khalack and F. LeBlanc

Département de Physique et d'Astronomie, Université de Moncton, Moncton, N.-B., Canada E1A 3E9

khalack.viktor@umoncton.ca

ABSTRACT

We present results for the estimation of gravity, effective temperature and radial velocity of poorly studied chemically peculiar stars recently observed with the spectropolarimeter ESPaDOnS at CFHT in the frame of the VeSElkA (Vertical Stratification of Element Abundances) project. For four of the stars from our sample (HD 23878, HD 83373, HD 95608 and HD 164584), the values of their effective temperature and surface gravity are determined for the very first time. Grids of stellar atmosphere models with the corresponding fluxes have been calculated using version 15 of the PHOENIX code for effective temperatures in the range of 5000K to 15000K, for the logarithm of surface gravities in the range of 3.0 to 4.5 and for the metallicities from -1.0 to +1.5. We have used these fluxes to fit the Balmer line profiles employing the code FITSB2 that produces estimates of the effective temperature, gravity and radial velocity for each star. When possible, our results are compared to those previously published. The physical characteristics of 16 program stars are discussed with the future aim to study the abundance anomalies of chemical species and the possible vertical abundance stratification in their stellar atmosphere.

Subject headings: atomic processes – line: profiles – stars: abundances – stars: atmospheres – stars: chemically peculiar

1. Introduction

Despite of the fact that some chemically peculiar (CP) stars have ”stable” atmospheres, they sometimes also show variability of their spectra with the period of stellar rotation due to the horizontal inhomogeneous distribution of elements abundance in their stellar atmosphere (Khokhlova 1975). A significant fraction of CP stars shows signatures of strong magnetic fields (Bychkov et al. 2003) and their structure correlates with the patches of overabundance (or underabundance) of some elements (Kochukhov et al. 2002; Shavrina et al. 2010). It appears that the magnetic field can intensify accumulation or depletion of chemical elements at certain optical depths (Ryabchikova et al. 2008; Alecian & Stift 2010). Some stars also show vertical stratification of abundance of several chemical species (Savanov & Kochukhov 1998; Ryabchikova et al. 2004; Khalack et al. 2013), which can be explained in terms of the mechanism of atomic diffusion (Michaud 1970).

Accumulation or depletion of chemical elements at certain optical depths brought about by atomic diffusion can modify the structure of stellar atmospheres (Hui-Bon-Hoa et al. 2000; LeBlanc et al. 2009, 2010) and it is, therefore, important to gauge the intensity of such stratification. The slowly rotating CP stars with $V \sin i < 40$ km s^{-1} are good candidates to study the abundance stratification of elements with optical depth. Their small rotational velocities result in comparatively narrow and unblended line profiles which are well suitable for abundance analysis. Based on their slow rotation, we may assume the hypotheses of a hydrodynamically stable atmosphere in these stars which is necessary for the diffusion process to take place.

The diffusion velocities of different chemical

[1]Based on observations obtained at the Canada-France-Hawaii Telescope (CFHT) which is operated by the National Research Council of Canada, the Institut National des Sciences de l'Univers of the Centre National de la Recherche Scientifique of France, and the University of Hawaii.

Table 1: List of the observed slowly rotating CP stars.

Star	m_V	Δt (s)	S/N
HD 15385	6.2	1600	1100
HD 22920	5.5	920	1150
HD 23878	5.2	660	950
HD 53929	6.1	1160	1000
HD 68351	5.6	920	1100
HD 71030	6.1	1140	1100
HD 83373	6.4	1524	1000
HD 90277	4.7	520	1000
HD 95608	4.4	416	1300
HD 97633	3.3	152	1300
HD 110380	3.6	200	1300
HD 116235	5.9	1040	870
HD 164584	5.4	880	1300
HD 186568	6.0	1300	1000
HD 209459	5.8	1160	1000
HD 223640	5.2	680	1200

species depend on the relative values of gravity and radiative acceleration resulting from the momentum transfer from the radiation field to these chemical species (e.g. Gonzalez et al. 1995). The momentum transfer depends on the opacity of the species under consideration and on the local monochromatic radiation field, which, in turn, via the monochromatic opacities, depends on the local abundances of the different species. In a hydrodynamically stable atmosphere, the diffusion process may result in vertical stratification of chemical abundances. Detection of vertical abundance stratification of chemical species in atmospheres of slowly rotating CP stars is an indicator of the effectiveness of the diffusion mechanism responsible for the observed peculiarities of chemical abundances. Comparing the observed characteristics of vertical stratification of chemical abundances with the results of theoretical modeling will help to verify and improve the self-consistent models of stellar atmospheres. Such models were calculated with a modified version of the PHOENIX code (LeBlanc et al. 2009). These models were mostly applied to blue horizontal-branch stars (LeBlanc et al. 2010). Stift & Alecian (2012) also have calculated chemically stratified atmospheric models using the CARATSTRAT code applied to ApBp stars.

Vertical stratification of the chemical abundances in stars can be estimated through the analysis of multiple lines that belong to the same ion of the studied element (Khalack & Wade 2006; Khalack et al. 2007) using the ZEEMAN2 code (Landstreet 1988). This procedure was successfully implemented to detect vertical abundance stratification in the atmospheres of several blue horizontal-branch stars (Khalack et al. 2007, 2008, 2010).

Therefore, we have initiated a new project entitled ”Vertical Stratification of Elements Abundances” (VeSElkA - meaning rainbow in Ukrainian) aimed to search for, and study the signatures of abundance stratification of chemical species with optical depth in the atmospheres of slowly rotating CP stars. A list of suitable candidates has been compiled based on the catalog of Ap, HgMn and Am stars of **?**. From the very beginning, we have concentrated our attention on the relatively bright, slowly rotating and poorly studied CP stars that can be easily observed with ESPaDOnS (CFHT) in spectropolarimetric mode. Up to now, we have obtained high signal-to-noise ratio and high resolution spectra for a sample of selected CP stars (see Sec. 2) and found indication of vertical stratification of iron abundance in HD 95608 and HD 116235 (Khalack et al. 2013). Not all stars in our sample are expected to contain vertical stratification of elements in their atmosphere. For instance, AmFm stars are expected to have chemically homogeneous atmospheres due to convective mixing (Richer et al. 2000; Richard et al. 2001). Our analysis will however give estimates for the average abundances in the atmospheres of these stars. Such results could help confirm or disprove their classification as CP stars.

This paper aims to present results for the determination of the fundamental parameters ($T_{\rm eff}$ and $\log g$) as well as radial velocity of 16 selected stars. This is the first estimation of $T_{\rm eff}$ and $\log g$ for four of them. The observations and the reduction procedure are described in Section 2. The models used and the fitting procedure are discussed in Sections 3 and 4 respectively. The main results are presented in Section 5 together with the description of the properties of each studied star. A discussion follows in Section 6.

2. Observations

High resolution (R=65000) Stokes IV spectra of several CP stars with $V \sin i < 40$ km s^{-1} were obtained recently with ESPaDOnS (Echelle SpectroPolarimetric Device for Observations of Stars) employing the deep-depletion e2v device Olapa. ESPaDOnS

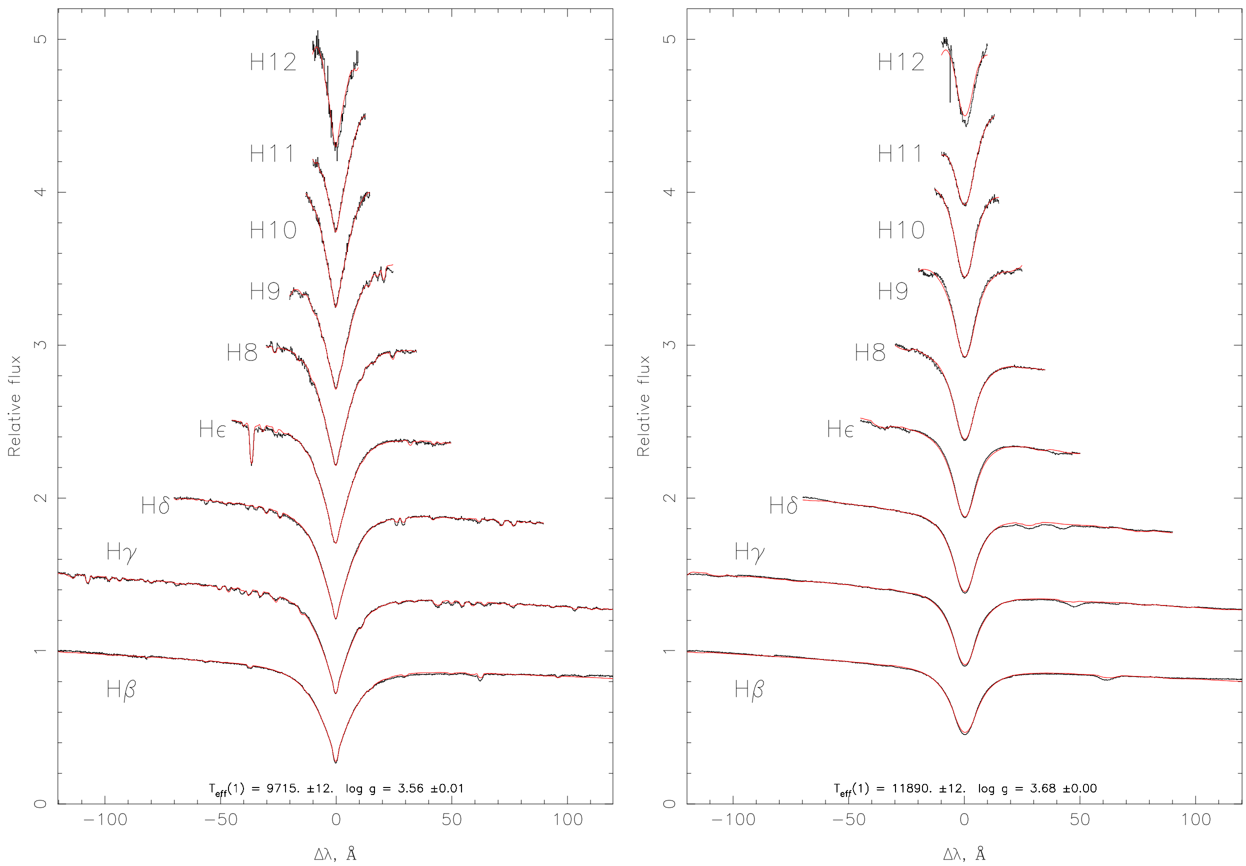

Fig. 1.— The observed spectra (thick line) of 108 Vir (left) and α Leo (right) are well fitted by synthetic spectra (thin dotted line) that corresponds to $T_{\rm eff}$ = 9715 K, log$g$ = 3.56, [M/H]= -0.5 (χ^2/ν = 2.64) and $T_{\rm eff}$ = 11890 K, log$g$ = 3.68, [M/H]= 0.0 (χ^2/ν = 12.26) respectively.

allows the acquisition of an essentially continuous spectrum throughout the spectral range from 3700Å to 10500Å in a single exposure (Donati et al. 1999). The optical characteristics of the spectrograph as well as the instrument performances are described by Donati et al. (2006)[2]. The obtained spectra were reduced using the dedicated software package Libre-ESpRIT (Donati et al. 1997) which yields both the Stokes I spectrum and the Stokes V circular polarisation spectrum. To infer the effective temperature and gravity of the observed stars, we have used their non-normalized spectra.

Table 1 presents a list of the observed slowly rotating chemically peculiar stars. The first and the second columns provide respectively the name of the star and its apparent visual magnitude, while the third and the forth columns contain the accumulation time and the maximal signal-to-noise ratio for the acquired Stokes I spectra.

3. Grid of models

A new library of high resolution synthetic spectra has been created in order to determine the effective temperature and gravity of stars observed in the frame of the project VeSElkA. A grid of stellar atmosphere models and corresponding fluxes have been calculated using version 15 of the PHOENIX code (Hauschildt et al. 1997) for 5000 K $\leqslant T_{\rm eff} \leqslant$ 15000 K and 3.0 $\leqslant \log g \leqslant$ 4.5. For the effective temperatures from 5000 K to 9000 K, we have used a 250 K step, while for the higher temperatures up to 15000 K

[2] For more details about this instrument, the reader is invited to visit www.cfht.hawaii.edu/Instruments/Spectroscopy/Espadons/

a 500 K step was used. The gravities have been calculated with a step 0.5. The theoretical fluxes have a resolution of 0.05Å in the visible range from 3700Å to 7700Å. We have calculated grids of models for solar metallicity (Grevesse et al. 2010) as well as for the metallicities [M/H]= -1.0, -0.5, +0.5, +1.0, +1.5. For all the grids, the microturbulent velocity is assumed to be zero. The synthetic spectra have been corrected for the air wavelength using the equation given by Morton (1991).

Exploiting the possibilities of the PHOENIX code (Hauschildt et al. 1997), we have calculated spherically symmetric models of stellar atmospheres for which the gravity depends on the stellar radius. In this case, all the structure of the atmosphere can be calculated knowing the effective temperature $T_{\rm eff}$, the surface gravity $\log g$ and the stellar mass M_*. For the given values of effective temperature and surface gravity, we have derived the respective stellar mass trough the interpolation of data for physical parameters of normal main-sequence stars (Popper 1980).

To verify the accuracy of the grids of stellar atmosphere models, we have used the spectra of α Leo (HD 87901) and 108 Vir (HD 129956)[3] obtained with ESPaDOnS in the spectropolarimetric mode. The profiles of nine Balmer lines in the non-normalised spectra of α Leo and 108 Vir have been fitted with the help of the FITSB2 code (Napiwotzki et al. 2004) using the grid of models calculated for the metallicity [M/H]=-0.5 and 0.0 respectively (see Fig. 1). In order to model a continuum in the vicinity of the analysed Balmer lines, the code FITSB2 uses a linear function fitted over the line profile region and the continuum as a part of the fitting procedure. This approach provides a better fit quality than the standard procedure in which one tries to fit the continuum regions (relatively free of lines) to the left and to the right of the analysed Balmer line profile separately (Napiwotzki 2014).

In the case of α Leo, assuming its $V \sin i$ = 300 km s^{-1} (Abt et al. 2002), the best fit is obtained for solar metallicity, $T_{\rm eff}$ = 11890 K and $\log g$ = 3.68, resulting in χ^2/ν = 12.26 (see right panel of the Fig. 1). A similar simulation that employs the grid of models calculated with PHOENIX-16 code (Husser et al. 2013) gives the best fit for the solar metallicity, $T_{\rm eff}$ = 11976 K and $\log g$ = 3.75 (χ^2/ν = 11.57). These results are close to each other and to the values $T_{\rm eff}$ = 11962 $\pm$ 115 K and $\log g$ = 3.56 obtained by Gray et al. (2003) from fitting low resolution spectra of α Leo and its photometric data. Meanwhile, using the Atlas9 grids[4] (Castelli & Kurucz 2004) to fit the Balmer line profiles in the same spectrum of α Leo, the best fit is obtained for the metallicity [M/H] = -0.3, $T_{\rm eff}$ = 12660 K and $\log g$ = 3.80 (χ^2/ν = 13.76). It appears that for α Leo the use of the Atlas9 grids leads to the best fit with comparatively higher value of χ^2/ν and to higher values of effective temperature and surface gravity.

In the case of 108 Vir, assuming its $V \sin i$ = 83 km s^{-1} (Ammler-von Eiff & Reiners 2012), the best fit is obtained for the metallicity [M/H]=-0.5, $T_{\rm eff}$ = 9715 K and $\log g$ = 3.56, resulting in χ^2/ν = 2.64 (see left panel of Fig. 1). The grids calculated with PHOENIX-16 code and the Atlas9 grids result in the best fits with [M/H] = -0.2, $T_{\rm eff}$ = 10280 K, $\log g$ = 3.86 (χ^2/ν = 2.57) and [M/H] = -0.3, $T_{\rm eff}$ = 9760 K, $\log g$ = 3.64 (χ^2/ν = 2.88) respectively. Our estimate of the effective temperature is close the one obtained with the Atlas9 grids and to $T_{\rm eff}$ = 9840 K found by Ammler-von Eiff & Reiners (2012), but is significantly smaller than the effective temperature obtained using the PHOENIX-16 grids (Husser et al. 2013). Our estimate of the surface gravity is similar to the one obtained for the Atlas9 grids but smaller than the one obtained with the PHOENIX-16 grids.

By comparing our results for α Leo and 108 Vir with the relatively well-established values for $T_{\rm eff}$ and $\log g$, we may roughly estimate the uncertainties of the results presented here as $\pm$200 K for effective temperature and $\pm$0.2 for surface gravity.

4. Fitting procedure

4.1. Sensitivity to the set of analysed Balmer lines

In order to study the sensitivity of the determined values of $T_{\rm eff}$ and $\log g$ to the set of analysed Balmer line profiles, we have compared the best fit results obtained when one of the Balmer lines is omitted from the analysis with the best fit results obtained from the analysis of all nine Balmer line profiles for HD 129956 (108 Vir) and HD 87901 (α Leo) using the Phoenix-15 grids and the Atlas9 grids. The fitting procedure have been performed with the help of FITSB2 code (Napiwotzki et al. 2004) employing the aforementioned grids of stellar atmosphere models together

[3] Spectra of 108 Vir and of α Leo where downloaded from the CADC database via http://www4.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/en/cfht/.

[4] The Atlas9 grids are available at the http://zuserver2.star.ucl.ac.uk/∼idh/NewGrids/Atlas9.C04/.

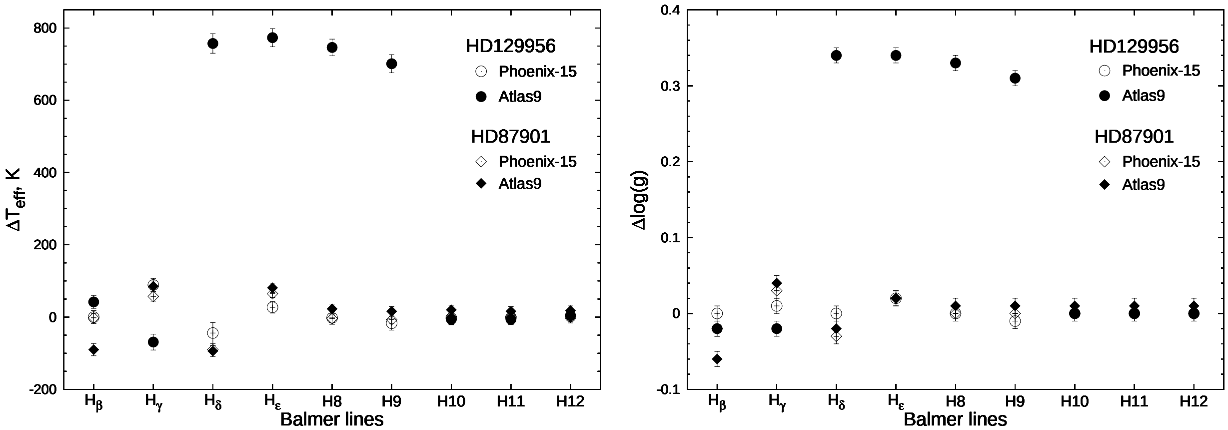

Fig. 2.— Variation of the best fit results obtained, when one of the Balmer lines (indicated at the X-axis) is omitted from the analysis, with respect to the values of $T_{\rm eff}$ (left) and $\log g$ (right) obtained from the analysis of all 9 Balmer line profiles (see Fig. 1) for HD 129956 (108 Vir) using the Phoenix-15 grids (open circles) and the Atlas9 grids (filled circles), and for HD 87901 (α Leo) using the Phoenix-15 grids (open diamonds) and the Atlas9 grids (filled diamonds). The error bars represent the internal errors of the fitting procedure with the FITSB2 code and are much smaller than the true errors (see Section 3).

with the respective simulated spectra. The left panel of Fig. 2 shows the differences between the values of $T_{\rm eff}$ obtained by omitting one of the Balmer lines from the analysis and the value of $T_{\rm eff}$ given in Section 3 for HD 129956 and HD 87901 respectively. The corresponding differences for $\log g$ are shown in the right panel of Fig. 2 for the same stars. In the case of $T_{\rm eff}$ and $\log g$, the zero difference corresponds to the respective values obtained using the Phoenix-15 grids and presented in Fig. 1 for each reference star. Meanwhile, the results shown in the Fig. 2 for the Atlas9 grids are compared to the corresponding values of stellar parameters found for the reference stars in Section 3 using the Atlas9 grids.

For HD 129956 (108 Vir), we can see that its best fit values of $T_{\rm eff}$ and $\log g$ jump up if one uses the Atlas9 grids and excludes from the analysis one of the following Balmer lines H_δ, H_ε, $H8$ or $H9$. Meanwhile, the use of the Phoenix-15 grids results in relatively small variation of $T_{\rm eff}$ and $\log g$ when one of these Balmer lines is excluded from the analysis.

In the case of HD 87901 (α Leo), application of the Atlas9 grids or of the Phoenix-15 grids leads, under the same conditions, to relatively small variations of $T_{\rm eff}$ and $\log g$ that do not exceed 100 K and 0.06 respectively (see Fig. 2). The errors chosen for $T_{\rm eff}$ ($\pm$200 K) and $\log g$ ($\pm$0.2) therefore seem reasonable. It appears that the use of the Phoenix-15 grids results in more stable best fit data for $T_{\rm eff}$ and $\log g$ with respect to the set of Balmer line profiles employed for the analysis. Meanwhile, the use of the Atlas9 grids may cause significant errors in the determination of fundamental stellar parameters if the effective temperature is close to 10000 K, depending on which set of Balmer lines is used.

The variations of $T_{\rm eff}$ and $\log g$ are most sensitive to the H_β, H_γ, H_δ, and H_ε Balmer lines when one employs the Phoenix-15 grids. It seems that this sensitivity does not vary much in the range of effective temperatures from 9700 K to 12000 K (see Fig. 2).

4.2. The best fit results

Nine Balmer line profiles have been fitted in the observed spectra of the selected slowly rotating CP stars to find their effective temperature and surface gravity. For each star, the fitting procedure has been performed for the metallicities [M/H]= -1.0, -0.5, 0.0, +0.5, +1.0 using the Phoenix-15 grids. Among the obtained results, the fundamental parameters associated to the fit with the smallest value χ^2/ν are chosen. These best fit results for effective temperature, surface gravity, radial velocity and metallicity are presented respectively in the second, third, fourth and fifth columns of Table 2 together with the fit quality in the sixth column. The values of the effective temperature and the surface gravity found for these stars by other authors are given

Table 2: Determined values of the effective temperature and the surface gravity for the programm CP stars.

Star	Balmer lines $T_{\rm eff}$ (K)	$\log g$	$V_{\rm r}$ (km s^{-1})	[M/H]	χ^2/ν	Previous publications $T_{\rm eff}$ (K)	$\log g$	$V \sin i$ (km s^{-1})
HD 15385	8230±200	4.00±0.2	22.0±1.0	0.0	0.65	8154[a]	4.12[a]	21[a], 29[b]
HD 22920	13640±200	3.74±0.2	20.0±2.0	-0.5	5.67	13700[c]	3.72[c]	30[d], 39[b]
HD 23878	8740±200	3.86±0.2	29.5±1.0	0.0	0.62			24[b]
HD 53929	13950±200	3.90±0.2	15.0±1.0	-1.0	3.20	14050±250[e]	3.60±0.25[e]	25[b], 30[e]
HD 68351	10080±200	3.22±0.2	18.1±1.0	0.0	1.17	10290±340[f]		33[b]
HD 71030	6780±200	4.04±0.2	38.1±1.0[h]	0.0	0.28	6541±47[g]	4.03±0.05[g]	9±2[h]
HD 83373	9800±200	3.81±0.2	26.5±1.0	0.0	0.92			28[b]
HD 90277	7250±200	3.62±0.2	14.5±1.0	0.0	1.29	7440[i]	3.46[i]	34[b]
HD 95608	9200±200	4.25±0.2	-10.4±1.0[h]	+0.5	0.59			21[b],17±2[h]
HD 97633	8750±200	3.45±0.2	8.2±1.0	0.0	0.61	8790±351[j]	3.59±0.89[j]	23[b]
HD 110380	6980±200	4.19±0.2	-17.6±1.0	0.0	0.31	6720[k]	4.20[k]	23[b]
HD 116235	8900±200	4.33±0.2	-10.3±1.0[h]	+0.5	0.49	8570[l]	4.23[l]	20±2[h]
HD 164584	6800±200	3.54±0.2	-11.2±1.0	0.0	1.16			
HD 186568	11070±200	3.44±0.2	-9.5±1.0	-0.5	1.81	11596±120[m]	3.39±0.15[m]	18[m]
HD 209459	10310±200	3.62±0.2	-0.3±1.0	0.0	0.97	10455±400[m]	3.52±0.15[m]	14[b]
HD 223640	12500±200	4.08±0.2	17.0±2.0	+1.0	1.65	12429±435[g]	3.93±0.23[g]	28[b]

Notes: [a]Künzli & North (1998), [b]Royer et al. (2002), [c]Catanzaro et al. (1999), [d]Leone & Manfrè (1996), [e]Smith & Dworetsky (1993), [f]Aurière et al. (2007), [g]Prugniel et al. (2011), [h]Khalack et al. (2013), [i]Berthet (1990), [j]Koleva & Vazdekis (2012), [k]Boesgaard & Trypicco (1986), [l]Erspamer & North (2003), [m]Hubrig & Castelli (2001)

in the seventh and eighth columns respectively. Meanwhile, the previously published values for $V \sin i$ are presented in the ninth column. Examples of best fits for HD 23878 and HD 164584, and for HD 95608 and HD 209459 are shown in Fig. 3 and Fig. 4 respectively.

5. Individual stars

5.1. HD15385

Künzli & North (1998) have classified HD 15385 (HR 723) as a A2m star having a mass $M_* = 1.85 M_\odot$ and age $\log t = 8.79 \pm 0.12$. Taking into account its relatively small value of rotational velocity $V \sin i = 29$ km s^{-1} (Royer et al. 2002), this star was chosen for the VeSElkA project. Our estimate of the effective temperature $T_{\rm eff} = 8230 \pm 200$ K and the surface gravity $\log g = 4.0 \pm 0.2$ are in good agreement with the values found by Künzli & North (1998) (see Tab. 2). Our estimate of the radial velocity for HD 15385 (see Tab. 2) is similar to the value of $V_{\rm r} = 21.3$ km s^{-1} obtained by Wilson (1953), but is significantly higher than the value $V_{\rm r} = 15$ km s^{-1} reported by Palmer et al. (1968).

5.2. HD22920

The silicon star HD 22920 (22 Eri, HR 1121) shows a weak photometric variability with the period P = $3^d.95$ (Bartholdy 1988) and the presence of a rather weak longitudinal magnetic field $B_{\rm l} = 310 \pm 160$ G (Bychkov et al. 2003). Catanzaro et al. (1999) have found $T_{\rm eff} = 13700$ K and $\log g = 3.72$ for this star. Similar parameters ($T_{\rm eff} = 13700$ K and $\log g = 3.72$) have been adopted by Leone & Manfrè (1996) to reproduce the observed spectrum of HD 22920. Our estimate of the effective temperature and the surface gravity (see Tab. 2) are consistent with these results. Meanwhile, the radial velocity $V_{\rm r} = 20.0 \pm 2.0$ km s^{-1} obtained in the present study seems to be higher than the previously reported values 16.4 ± 3.1 km s^{-1} (Leone & Manfrè 1996; Wielen et al. 2000) and 17.2 ± 0.7 km s^{-1} (Gontcharov 2006). From the analysis of HD 22920 spectra, Leone & Manfrè (1996) have also found its rotational velocity $V \sin i = 30$ km s^{-1}.

We have acquired several Stokes IV spectra for this star that show a strong variability of Si II, Ti II, Cr II, Fe II line profiles with rotational phase, while Mg II and He I line profiles seem to be less variable. Our high S/N spectra (see Tab. 1) reveal a weak variability of

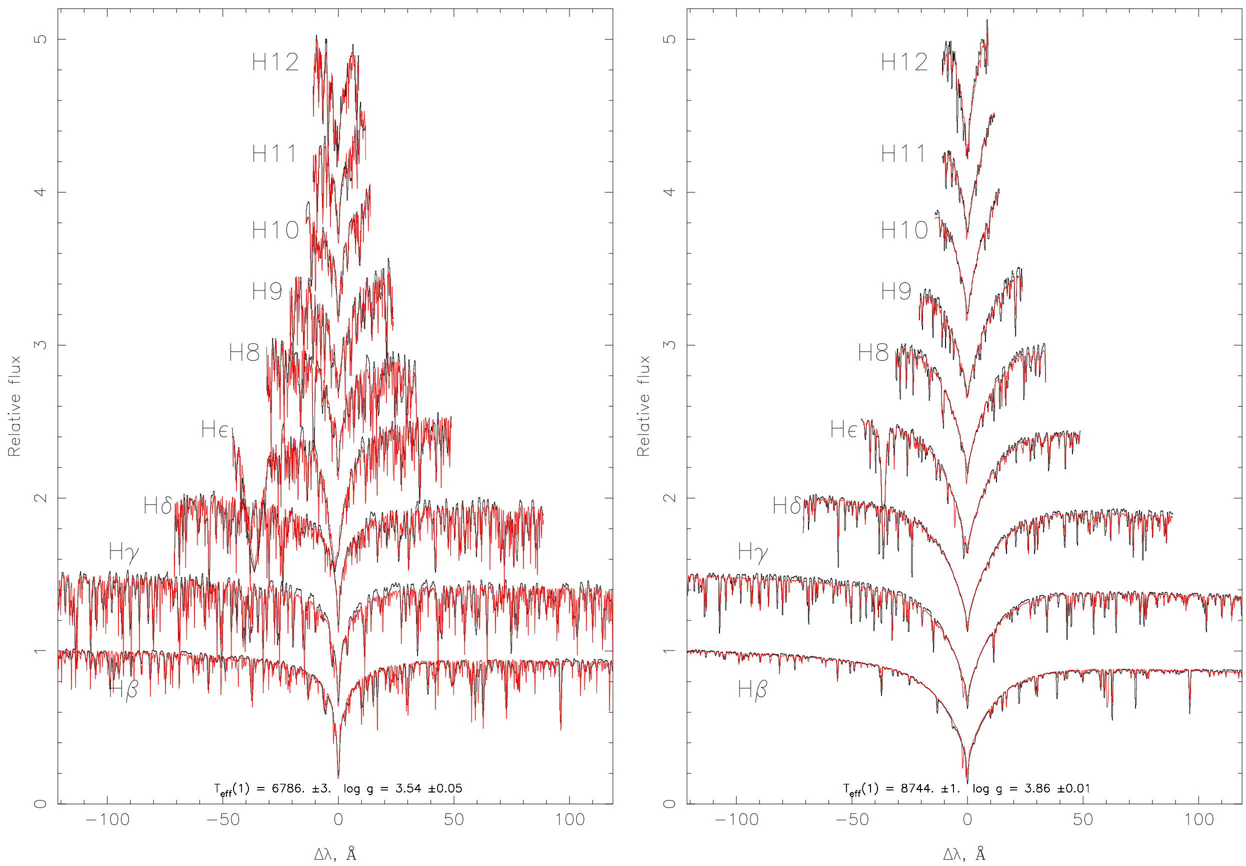

Fig. 3.— The observed spectrum (thick line) of HD 164584 (left) and HD 23878 (right) is well fitted by synthetic spectrum (thin dotted line) that corresponds to $T_{\rm eff}$ = 6800 K, $\log g$ = 3.54 (χ^2/ν = 1.16) and $T_{\rm eff}$ = 8740 K, $\log g$ = 3.86 (χ^2/ν = 0.62) respectively.

the He I 5876Å line profile for which Catanzaro et al. (1999) have found no variability.

5.3. HD 23878

Based on the measurement of the anomalously low line strength ratio Sc II 4246Å/Sc II 4215Å, Conti (1965) has suggested that HD 23878 might be an Am star. HD 23878 (28 Eri, HR 1181) appears to be a low amplitude variable star with a period of about $7^d.17$ (Mathys et al. 1985) having a rotational velocity $V \sin i$ = 24 km s^{-1} (Royer et al. 2002). Meanwhile, Abt & Morrell (1995) have reported $V \sin i$ = 18 km s^{-1} for this star. HD 23878 has not previously been studied spectroscopically in detail and the fitting of the Balmer line profiles (see right panel at the Fig. 3) results in $T_{\rm eff}$ = 8740±200 K and $\log g$ = 3.86±0.20. Our estimate of radial velocity is in agreement with the value $V_{\rm r}$ = 28.4±0.5 km s^{-1} obtained by Gontcharov (2006) (see Tab. 2).

5.4. HD 53929

HD 53929 is a HgMn star with mild but significant enhancement of manganese abundance $\log N_{\rm Mn}/N_{\rm H}$ = -5.85±0.20 (Smith & Dworetsky 1993) and with a mercury abundance $\log N_{\rm Hg}/N_{\rm H}$ = -9.90±0.20 at the level of normal stars (Smith 1997). This star has also much lower abundance of chromium, cobalt and nickel as compared to their solar abundances (Smith & Dworetsky 1993). The analysis of Balmer line profiles in the single spectrum available for HD 53929 results in an effective temperature which is in good agreement with the temperature obtained by Smith & Dworetsky (1993) (see Tab. 2). Meanwhile, our estimate of the surface gravity $\log g$ = 3.90±0.20

seems to be a little higher than the value $\log g$ = 3.60±0.25 reported by Smith & Dworetsky (1993).

Royer et al. (2002) have obtained $V \sin i$ = 25 km s^{-1} for HD 53929. Its radial velocity increased over the last 50 years going from 6.1 km s^{-1} (Evans 1967; Hube 1970), to 11.2±1.3 km s^{-1} (Gontcharov 2006) and to 15.0±1.0 km s^{-1} found in this study. Is seems that HD 53929 may be a member of a long periodic double system.

5.5. HD 68351

In the catalog of Renson & Manfroid (2009), this object is classified as a star of spectral class A0 with the strong lines of Si and Cr. According to Abt & Morrell (1995), the rotational velocity of HD 68351 is $V \sin i$ = 25 km s^{-1}, while Royer et al. (2002) and Aurière et al. (2007) have reported $V \sin i$ = 33 km s^{-1}. Its rotational period $P = 4^d.116$ was determined by Stepień (1968). In this study, we present the results for its fundamental parameters $T_{\rm eff}$ = 10080±200 K and $\log g$ = 3.22±0.20 based on the analysis of Balmer line profiles which are in agreement with the data previously published by Aurière et al. (2007) for this star. Our estimate of the radial velocity seems to be a little smaller than the value $V_{\rm r}$ = 19.9 km s^{-1} obtained by Evans (1967) (see Tab. 2).

Taking into account the high values of luminosity $L_* = 466 \pm 225 L_\odot$ and radius $R_* = 6.6 \pm 2.4 R_\odot$ of HD 68351 (Aurière et al. 2007) and its low surface gravity $\log g$ = 3.22±0.20, this star is beyond the end of the main sequence and most probably belongs to the III luminosity class. Aurière et al. (2007) have detected the presence of a longitudinal magnetic field $B_l = 325 \pm 45$ G from the analysis of HD 68351 LSD profiles.

For this star, we have obtained two Stokes IV spectra with a time gap of 2 days. The Stokes I spectrum of HD 68351 appears to be strongly variable, while the Stokes V does not show signatures of the presence of a strong magnetic field. This is consistent with the results of Aurière et al. (2007) that have observed HD 68351 15 times, but have found the magnetic field signatures in only 5 spectra. A preliminary analysis of the two obtained spectra results in slightly different values of radial velocity $V_{\rm r}$ = 18.1±1.0 km s^{-1} and 14.7±1.0 km s^{-1} that can be an indicator of possible binarity of HD 68351.

5.6. HD 71030

Cenarro et al. (2007) have reported HD 71030 (25 Cnc, HR 3299) to be a main-sequence star of spectral class F6. Based on the analysis of a low resolution spectrum, Balachandran (1990) has reported higher than solar lithium abundance $\log N_{\rm Li}/N_{\rm H}$ = -9.37 and slightly underabundant iron $\log N_{\rm Fe}/N_{\rm H}$ = -4.80±0.05 for this star. Meanwhile, Khalack et al. (2013) have found nearly solar abundance of Fe II $\log N_{\rm Fe}/N_{\rm H}$ = -4.43±0.34, Cr II $\log N_{\rm Cr}/N_{\rm H}$ = -6.27±0.09 and Ni I $\log N_{\rm Ni}/N_{\rm H}$ = -5.77±0.26. They have also found that Fe, Cr and Ni are uniformly distributed with respect to optical depth in the atmosphere of this star.

Our estimation of the surface gravity for HD 71030 is the same as the value $\log g$ = 4.03±0.05 published by Prugniel et al. (2011) (see Tab. 2), while our estimation of the effective temperature $T_{\rm eff}$ = 6780±200 K seems to be slightly higher as compared to the results of Prugniel et al. (2011) (but within the given error bars). The value for the radial velocity determined in this work is in agreement with the previously obtained results of 37.4 km s^{-1} (Nordström et al. 2004) and 37.1±0.4 km s^{-1} (Gontcharov 2006). The estimate of $V \sin i$ = 9±2 km s^{-1} (Khalack et al. 2013) is also in good agreement with the value $V \sin i$ = 8 km s^{-1} provided by Balachandran (1990).

5.7. HD 83373

HD 83373 (34 Hya, HR 3832) is reported by Renson & Manfroid (2009) as a chemically peculiar star of spectral class A1 that has an enhanced silicon abundance. Royer et al. (2002, 2007) have measured its rotational velocity $V \sin i$ = 28 km s^{-1}. This star has not been previously studied spectroscopically and we provide here first estimates of its effective temperature $T_{\rm eff}$ = 9800±200 K and surface gravity $\log g$ = 3.81±0.20. Our estimate of the radial velocity for HD 83373 (see Tab. 2) is in good agreement with the value $V_{\rm r}$ = 26.9±0.5 km s^{-1} reported by Gontcharov (2006).

5.8. HD 90277

Abundance analysis of HD 90277 (HR 4090) has been performed by Berthet (1990) who has found a strong overabundance of Y, Zr and Ba, while Ti, Cr, Mn, Fe and Ni appear to be slightly overabundant. Royer et al. (2002, 2007) have reported $V \sin i$ = 34 km s^{-1} for HD 90277. Our estimates of the effective temperature and the surface gravity are similar to the

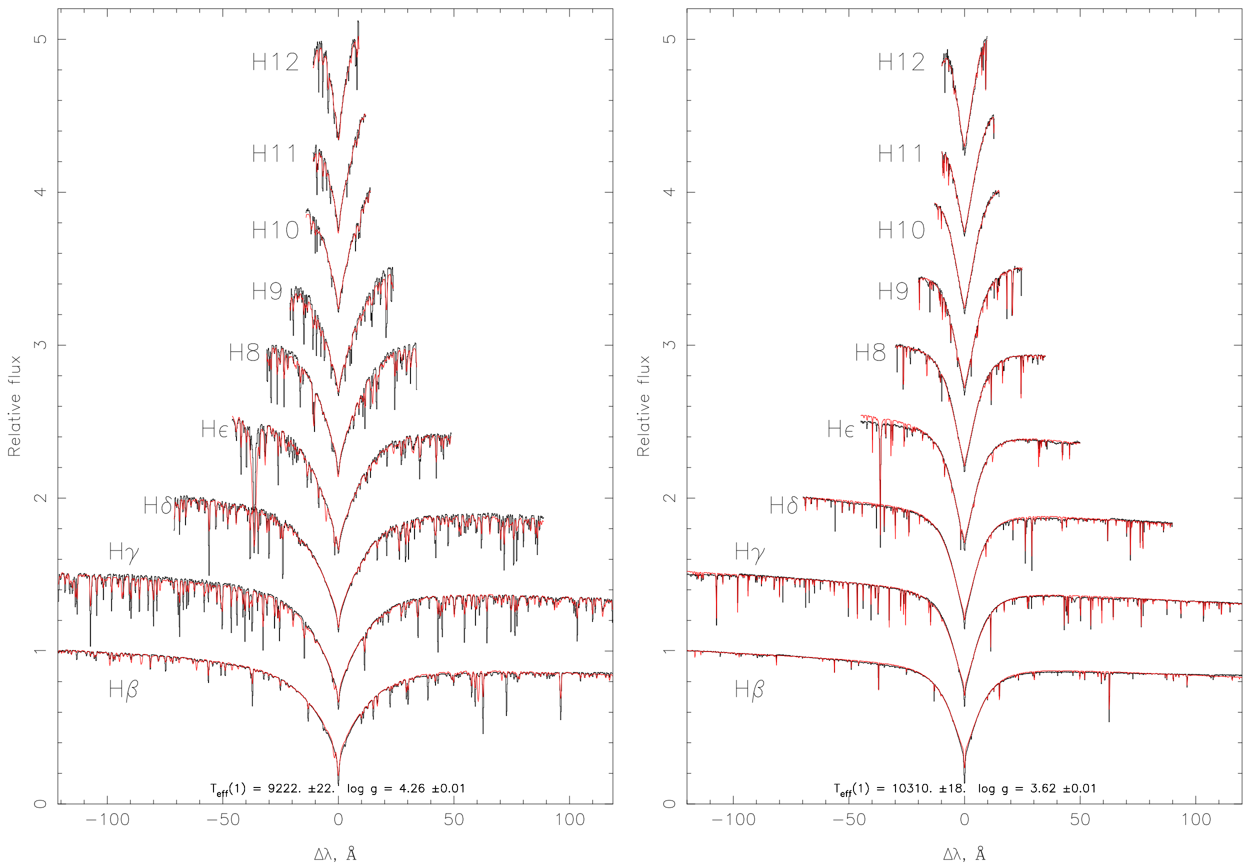

Fig. 4.— The observed spectrum (thick line) of HD 95608 (left) and HD 209459 (right) is well fitted by synthetic spectrum (thin dotted line) that corresponds to $T_{\rm eff}$ = 9200 K, $\log g$ = 4.26 (χ^2/ν = 0.59) and $T_{\rm eff}$ = 10310 K, $\log g$ = 3.62 (χ^2/ν = 0.97) respectively.

values obtained by Berthet (1990) taking into account the error bars (see Tab. 2). The value for the radial velocity determined in this work agrees well with the previously obtained result $V_{\rm r}$ = 13.7 km s^{-1} (Evans 1967) and 13.7$\pm$0.6 km s^{-1} Gontcharov (2006).

5.9. HD 95608

Cowley et al. (1965) have classified HD 95608 (60 Leo, HR 4300) as a CP star of spectral class A1m. From the fitting of Balmer line profiles of HD 95608 (see left panel of Fig. 4), we have found its effective temperature $T_{\rm eff}$ = 9200$\pm$200 K and surface gravity $\log g$ = 4.25$\pm$0.20 (see Tab. 2). The value for radial velocity determined in this work $V_{\rm r}$ = -10.4$\pm$1.0 km s^{-1} agrees well with the previously obtained results -10.1 km s^{-1} (Wielen et al. 2000) and -11.1$\pm$0.7 km s^{-1} (Gontcharov 2006). The rotational velocity $V \sin i$ = 17.2$\pm$2.0 km s^{-1} obtained by Khalack et al. (2013) for HD 95608 seems to be smaller than the value $V \sin i$ = 21 km s^{-1} reported by Royer et al. (2002), but higher than $V \sin i$ = 13 km s^{-1} published by Abt & Morrell (1995).

Preliminary abundance analysis has shown that Ti II is slightly underabundant, while Fe I, Fe II are overabundant in this star as compared to their solar abundance (Khalack et al. 2013). This same study has also found that iron abundance appears to be vertically stratified in the stellar atmosphere of HD 95608.

5.10. HD 97633

Renson & Manfroid (2009) have classified HD 97633 (θ Leo, HR 4359) as a CP star of spectral class A2 that has enhanced Sr and Eu abundances (Hill 1995). Royer et al. (2002) have found $V \sin i$ = 23 km s^{-1} for

this star. Our estimates of its effective temperature and surface gravity (see Tab. 2) are in good agreement with the results obtained by Koleva & Vazdekis (2012). The radial velocity V_r = 8.2±1.0 km s^{-1} found in this work is consistent with the value V_r = 7.3 km s^{-1} reported by Gontcharov (2006).

5.11. HD 110380

HD 110380 (HR 4826) is in a binary system with HD 110379 with an orbital period P=171.4yr and a separation a=3.75″. HD 110380 has $V \sin i$ = 23 km s^{-1} (Royer et al. 2002) and an enhanced lithium abundance (Boesgaard & Trypicco 1986). Our estimate of its effective temperature seems to be a little higher than the value $T_{\rm eff}$ = 6720 K obtained by Boesgaard & Trypicco (1986), but the surface gravity is in good agreement with the value $\log g$ = 4.2 they found (see Tab. 2). The value for the radial velocity determined in this work V_r = -17.6±1.0 km s^{-1} is consistent with the value V_r = -19.5 km s^{-1} obtained by Nordström et al. (2004).

5.12. HD 116235

Cowley et al. (1965) have classified HD 116235 (HR 5040, 64 Vir) as a CP star of spectral class A2m. The effective temperature $T_{\rm eff}$ = 8900±200 K obtained in this study for HD 116235 appears to be higher than the previously published values 8570 K (Erspamer & North 2003) and 8373 K (Ammler-von Eiff & Reiners 2012). Meanwhile, the surface gravity obtained here is similar to $\log g$ = 4.23 reported by Erspamer & North (2003). The estimate of $V \sin i$ = 20±2.0 km s^{-1} (Khalack et al. 2013) is in a good agreement with the value 19.3±1.0 km s^{-1} obtained by Ammler-von Eiff & Reiners (2012) for this star. The radial velocity V_r = -10.3±1.0 km s^{-1} obtained in this study is consisted with the previously published values -10.2 km s^{-1} (Wilson 1953) and -8.4±2.3 km s^{-1} (Gontcharov 2006).

A preliminary abundance analysis of this star shows an enhanced abundance of Ni I, Fe I, Fe II, Cr I and Cr II (Khalack et al. 2013) in agreement with the results of Erspamer & North (2003), who have also reported a strong overabundance of Sr, Y and Ba. Moreover, Khalack et al. (2013) have also found signatures of vertical stratification of iron abundance in the atmosphere of HD 116235.

5.13. HD 164584

Renson & Manfroid (2009) have reported that HD 164584 (7 Sgr, HR 6724) has a spectral class A6-F4. From the analysis of Balmer line profiles (see left panel of Fig. 3), we have obtained $T_{\rm eff}$ = 6800±200 K and $\log g$ = 3.54±0.20.

Our estimate of radial velocity (see Tab. 2) is in good agreement with the value V_r = -11.2±1.6 km s^{-1} obtained by Gontcharov (2006) for this star.

5.14. HD 186568

HD 186568 (HR 7512) belongs to the normal B-type stars (B9 II) (Hubrig & Castelli 2001). Nevertheless, it was included by **?** to the list of chemically peculiar stars. From the analysis of equivalent widths of iron line profiles Hubrig & Castelli (2001) have found its solar abundance in the atmosphere of this star.

The effective temperature obtained for HD 186568 in this study is smaller than the value derived by Hubrig & Castelli (2001), while our value for the surface gravity is almost the same as the one determined by these authors (see Tab. 2). Our estimate for radial velocity is close to V_r = -8.8±0.1 km s^{-1} reported by Gontcharov (2006) and to the value -8.0±1.4 km s^{-1} reported by Morrell & Abt (1992) who have used this star as a radial velocity standard.

5.15. HD 209459

HD 209459 (21 Peg, HR 8404) is a normal B-type star (B9.5 V) which is often used as a comparison star (Dworetsky & Budaj 2000) because of its sharp-lined spectrum with $V \sin i$ = 4 km s^{-1} (Smith 1992) and absence of chemical abundance peculiarities. Based on the analysis of equivalent widths of iron line profiles in the spectrum of HD 209459, Hubrig & Castelli (2001) have found an iron abundance that is close to its solar value. We also aim to use this object as a comparison star in the VeSElkA project.

Our estimate of effective temperature and surface gravity (see Tab. 2) obtained from the analysis of Balmer line profiles (see right panel of Fig. 4) is in agreement with the previously published results $T_{\rm eff}$ = 10455±400 K, $\log g$ = 3.52±0.15 of Hubrig & Castelli (2001), but smaller than the results $T_{\rm eff}$ = 11015±301 K, $\log g$ = 3.99±0.12 reported by Prugniel et al. (2011). The radial velocity found in this study (see Tab. 2) is also in a good agreement with the value V_r = 0 km s^{-1} reported by Smith (1992).

5.16. HD 223640

Renson & Manfroid (2009) have reported HD 223640 (108 Aqr, HR 9031) as a CP star of spectral class B9. It shows an overabundance of Si, Sr and Cr (North et al. 1992). Bailey & Landstreet (2013) have found $V \sin i$ = 31±3 km s^{-1} for this star and that Cr and Si abundances exceed their respective solar values more than by 1 dex. Analysis of polarization in Balmer lines reveals the presence of a longitudinal magnetic field B_l = 643±218 G (Bychkov et al. 2003) which varies with period P = $3^d.73$ (North et al. 1992). The same period P = $3^d.735239 \pm 0^d.000024$ has been found by North et al. (1992) from photometric variability of HD 223640.

The effective temperature and the surface gravity obtained in this study (see Tab. 2) are in good agreement with the results of Prugniel et al. (2011), but seem to be slightly different (but still inside the error bars) with respect to the values $T_{\rm eff}$ = 12300±500 K, $\log g$ = 4.4±0.2 reported by Bailey & Landstreet (2013). Our estimate of the radial velocity seems to be larger (but still within the error bars) than the value V_r = 12.7±2.8 km s^{-1} reported by Gontcharov (2006).

6. Discussion

Based on the catalogue of Ap, HgMn and Am stars (**?**) and the available measurement of rotational velocities of CP stars (Royer et al. 2002, 2007) we have compiled a list of CP stars (see Table 1) suitable for search of signatures of abundance stratification of chemical species with respect to optical depth in their atmospheres. These stars have been recently observed in the frame of VeSElkA project with the ESPaDOnS at CFHT. The method developed for the analysis of vertical stratification of chemical abundance (Khalack & Wade 2006) allows to determine the slope of abundance change relative to optical depth.

In order to study the vertical stratification of chemical abundance one needs to adopt an appropriate model for the stellar atmosphere and to determine its parameters like effective temperature, surface gravity and metallicity. We were able to derive these parameters for the listed stars (see Table 2) based on the analysis of nine Balmer lines (see, for example, Fig. 3 and Fig. 4) using the FITSB2 code (Napiwotzki et al. 2004) that employs a grid of theoretical fluxes calculated for different values of $T_{\rm eff}$, $\log g$ and metallicity. Taking into account that the resolution R=65000 of the ESPaDOnS spectra, we have calculated a new library of synthetic spectra with a similar spectral resolution to properly fit the profiles of nine Balmer lines of stars observed in the frame of the project VeSElkA (see Section 4). Grids of stellar atmosphere models and corresponding fluxes have been calculated with the PHOENIX code (Hauschildt et al. 1997) for 5000 K $\leqslant T_{\rm eff} \leqslant$ 15000 K and $3.0 \leqslant \log g \leqslant 4.5$ for the metallicities [M/H]= -1.0, -0.5, +0.5, +1.0, +1.5.

We have used the spectra of 108 Vir (HD 129956) and α Leo (HD 87901) obtained with ESPaDOnS in the spectropolarimetric mode to verify the accuracy of our grids of synthetic fluxes. The results obtained for for these reference stars are close to the previously published data for their effective temperature and surface gravity (see Section 3).

In order to study the sensitivity of the determined values of $T_{\rm eff}$ and $\log g$ to the set of Balmer lines used, we have compared the best fit results obtained when one of the Balmer lines is omitted from the analysis with the best fit results obtained from the analysis of all nine Balmer line profiles for the reference stars using the Phoenix-15 and Atlas9 grids. We have found that the use of the Atlas9 grids may produce some ambiguity in the determination of fundamental stellar parameters if the effective temperature is close to 10000 K depending on which set of Balmer lines is used. Employing our Phoenix-15 grids for simulations with different sets of Balmer lines, we have shown that the estimates of $T_{\rm eff}$ and $\log g$ are most sensitive to the H_β, H_γ, H_δ, and H_ε Balmer lines. This sensitivity does not change significantly in the range of effective temperatures from 9700 K to 12000 K (see Fig. 2).

We roughly estimate the uncertainties ±200 K and ±0.2 respectively for the values of effective temperature and surface gravity. The relatively small variabilities found for $T_{\rm eff}$ and $\log g$ when using subsets of Balmer lines (see Subsection 4.1), seem to show that this choice for the errors is reasonable. It should be also noted that Husser et al. (2013) have calculated grids of theoretical fluxes for $T_{\rm eff}$ below 12000 K. Therefore we can not use those grids to determine $T_{\rm eff}$ and $\log g$ of all the stars selected for this study because some of them are much hotter than 12000 K (see Table 2). Meanwhile, our grids of synthetic spectra provide similar results as the grids of Husser et al. (2013) for the selected stars with $T_{\rm eff}$ below 12000 K. Since our grids go up to $T_{\rm eff}$ = 15000 K, they can be applied for all of the stars in our sample.

Our final results for effective temperature and surface gravity obtained for twelve of the stars presented

in Table 2 are consistent with the previously published data. For four other stars (HD 23878, HD 83373, HD 95608 and HD 164584), this study gives the first estimates of their $T_{\rm eff}$ and $\log g$.

It should be noted that some stars observed in the frame of the project VeSElkA have low $T_{\rm eff}$ (see Table 2) and won't have vertical stratification of chemical species due to the presence of mixing due to convection (Richer et al. 2000; Richard et al. 2001). Nevertheless, they provide the possibility to verify the validity of the method applied to analyse the vertical stratification of chemical abundances (Khalack & Wade 2006) and to determine their abundance peculiarities. For instance, Khalack et al. (2013) found no signatures of vertical stratification in HD 71030 and that the abundance of the analysed chemical species is close to their solar abundance. Our sample of analysed stars includes the reference stars HD 186568 and HD 209459 known to be a normal B-type stars (Dworetsky & Budaj 2000) without abundance peculiarities (Hubrig & Castelli 2001). These stars can also be used to verify the applied method and also to test the results for average abundances as well. The abundance analysis for all stars, even those where no stratification is found or expected, will be presented in upcoming papers. This analysis may be useful to confirm or disprove their CP type classification.

Khalack et al. (2013) have already analysed several of the selected stars with the aim to detect vertical stratification of chemical abundances in their atmospheres and found signatures of vertical stratification of iron in HD 95608 and HD 116235. A detailed abundance analysis for the other stars of our sample is underway. We also plan to add more suitable stars to the project VeSElkA. A large amount of observational data relative to the vertical abundance stratification of chemical species obtained for CP stars with different effective temperatures will allows us to search for a dependence of the vertical abundance stratification relative to the effective temperature, similar to the one that we have found for BHB stars (LeBlanc et al. 2010; Khalack et al. 2010). Our results will also be useful for comparison with theoretical modelling of vertical abundance stratification in stellar atmospheres (i.e. LeBlanc et al. 2009; Stift & Alecian 2012) and to better understand the diffusion process in the atmospheres of certain CP stars.

Acknowledgments

We are sincerely grateful to Ralf Napiwotzki and to John Landstreet for fruitful discussions and suggestions that lead to a significant improvement of this work. We thank Faculté des Études Supérieures et de la Recherche de l'Université de Moncton and NSERC for research grants. The calculations have been carried out on the supercomputer *briarree* of l'Université de Montréal, under the guidance of Calcul Québec and Calcul Canada. The use of this supercomputer is funded by the Canadian Foundation for Innovation (CFI), NanoQuébec, RMGA and Research Fund of Québec - Nature and Technology (FRQ-NT). This paper has been typeset from a TEX/LATEX file prepared by the authors.

REFERENCES

Abt H.A., Morrell N.I., 1995, ApJSS, 99, 135

Abt H.A., Levato H., Grosso M., 2002, ApJ, 573, 359

Alecian G., Stift M.J., 2010, A&A, 516, 53

Ammler-von Eiff M., Reiners A., 2012, A&A, 542, 116

Aurière M., Wade G. A., Silvester J., et al., 2007, A&A 475, 1053

Bailey J.D., Landstreet J. D., 2013, A&A, 551, 30

Balachandran S., 1990, ApJ, 354, 310

Bartholdy P., in: Halbwachs J.-L., Jasniewicz G., Egret D. (eds.), Comptes Rendus des Journées de Strasbourg, 10-me reunion, 21 April 1988, p.77

Berthet S., 1990, A&A, 227, 156

Boesgaard A.M., Trypicco M.J., 1986, AJ, 303, 724

Bychkov V.D., Bychkova L.V., Madej J. 2003, A&A, 407, 631

Catanzaro G., Leone F., Catalano F.A., 1999, A&ASS, 134, 211

Castelli F., Kurucz R.L., 2004, in Piskunov N. et al. eds, Proc. IAUS 210, A20

Cenarro A.J., Peletier R.F., Sanchez-Blazquez P., et al., MNRAS, 374, 664

Conti P.S., 1965, ApJ, 142, 1594

Cowley A., Cowley C., Jaschek M., Jaschek C., 1969, AJ, 74, 375

Donati J.-F., Catala C., Landstreet J.D., Petit P., 2006, in Casini R. & Lites B.W., eds., ASP-CS, 358, 362

Donati J.-F., Catala C., Wade G.A., et al., 1999, A&ASS, 134, 149

Donati J.-F., Semel M., Carter B.D., et al., 1997, MNRAS, 291, 658

Dworetsky M. M., Budaj J., 2000, MNRAS, 318, 1264

Evans D.C., 1967, IAUS 30, 57.

Erspamer D., North P., 2003, A&A, 398, 1121

Gontcharov G.A., 2006, PAZh, 32, 844

Gonzalez J.-F., LeBlanc F., Artru M.-C., Michaud G., 1995, A&A, 297, 223

Gray R.O., Corbally C.J., Garrison R.F., et al., 2003, AJ, 126, 2048

Grevesse N., Asplund M., Suaval A.J., Scott P., 2010, Ap&SS, 328, 179

Hauschildt P. H., Baron E., Allard F., 1997, ApJ, 483, 390

Hill G.M., 1995, A&A, 294, 536

Hube D. P., 1970, MNRAS, 72, 233

Hubrig S., Castelli F., 2001, A&A, 375, 963

Hui-Bon-Hoa A., LeBlanc F., Hauschildt P. H., 2000, ApJ, 535, L43

Husser T.-O., Wende-von Berg S., Dreizler S., et al., 2013, A&A, 553, 6

Khalack V., Wade G., 2006, A&A, 450, 1157

Khalack V.R., LeBlanc F., Behr B.B., 2010, MNRAS, 407, 1767

Khalack V.R., LeBlanc F., Behr B.B., Wade G.A., Bohlender D., 2008, A&A, 477, 641

Khalack V., LeBlanc F., Bohlender D., Wade G., Behr B. B., 2007, A&A, 466, 667

Khalack V., Yameogo B., Thibeault C., LeBlanc F., 2013, in Petit P., eds, Proc. IAUS 302, 272

Koleva M., Vazdekis A., 2012, A&A, 538, 143

Kochukhov O., Piskunov N., Ilyin I., et al., 2002, A&A, 389, 420

Khokhlova V.L., 1975, Astron. Zh., 52, 950

Künzli M., North P., 1998, A&A, 330, 651

Landstreet J. D., 1988, ApJ, 326, 967

LeBlanc F., Monin D., Hui-Bon-Hoa A., Hauschildt P.H., 2009, A&A, 495, 337

LeBlanc F., Hui-Bon-Hoa A., Khalack V.R., 2010, MNRAS, 409, 1606

Leone F., & Manfrè M., 1996, A&A, 315, 256

Mathys G., Manfoid J., Heck A., 1985, IBVS, 2738, 1

Michaud G., 1970, ApJ, 160, 641

Morrell, N., & Abt, H.A. 1992, ApJ, 393, 666

Morton D.C., 1991, ApJS, 17, 119

Napiwotzki R., 2014, private communication

Napiwotzki R., Yungelson L., Nelemans G. et al. 2004, in: Hilditch R. W., Hensberge H. & Pavlovski K., eds, ASP-CS (ASP. San Francisco), 318, 402

Nordström B., Mayor M., Andersen J., et al., 2004, A&A, 418, 989

North P., Brown D.N., Landstreet J.T., 1992, A&A, 258, 389

Palmer D.R., Walker E.N., Jones D.H.P., Wallis R.E., 1968, R. Obs. Bull., 135, 385

Popper D.M., 1980, ARA&A, 18, 115

Prugniel Ph., Vauglin I., Koleva M., 2011, A&A, 531, 165

Renson P., & Manfroid J, 2009, A&A, 498, 961

Richard O., Michaud G., Richer J., 2001, ApJ, 558, 377

Richer J., Michaud G., Turcotte S., 2000, ApJ, 529, 338

Ryabchikova T., Leone F., Kochukhov O., Bagnulo S., 2004, in: Zverko J., Ziznovsky J., Adelman S.J., & Weiss W.W., eds, Proc. of IAU Symp. N224, 580

Ryabchikova T., Kochukhov O., Bagnulo S. 2008, A&A, 480, 811

Royer F., Grenier S., Baylac M.-O., Gomez A.E., Zorec J., 2002, A&A, 393, 897

Royer F., Zorec J., Gomez A.E., 2007, A&A, 463, 671

Savanov I.S., & Kochukhov O.P. 1998, Astronomy Letters, 24, 516

Shavrina A.V., Glagolevskij Yu.V., Silvester J., et al., 2010, MNRAS, 401, 1882

Smith K.C., 1992, PhD thesis, University of London

Smith K.C., 1997, A&A 319, 928

Smith K.C., Dworetsky M.M., 1993, A&A, 274, 335

Stepień K. 1968, ApJ, 154, 945

Stift M.J., Alecian G., 2012, MNRAS, 425, 2715

Wielen R., Schwan H., Dettbarn C., et al. 2000, Veroeff. Astron. Rechen-Inst. Heidelberg, 37, 1

Wilson R.E., 1953, General Catalogue of Stellar Radial Velocities, Carnegie Institution of Washington, 601

This 2-column preprint was prepared with the AAS LaTeX macros v5.2.